

Tilburg University

The influence of mental fatigue on facial EMG activity during a simulated workday

Veldhuizen, I.J.T.; Gaillard, A.W.K.; de Vries, J.

Published in:
Biological Psychology

Publication date:
2003

Document Version
Publisher's PDF, also known as Version of record

[Link to publication in Tilburg University Research Portal](#)

Citation for published version (APA):
Veldhuizen, I. J. T., Gaillard, A. W. K., & de Vries, J. (2003). The influence of mental fatigue on facial EMG activity during a simulated workday. *Biological Psychology*, 63(1), 59-78.

General rights

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal

Take down policy

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.



The influence of mental fatigue on facial EMG activity during a simulated workday

I.J.T. Veldhuizen^{a,*}, A.W.K. Gaillard^{a,b}, J. de Vries^a

^a *Tilburg University, Warandelaan 2, P.O. Box 90153, 5000 LE Tilburg, The Netherlands*

^b *TNO Human Factors, Soesterberg, Kampweg 5, P.O. Box 23, 3769 ZG Soesterberg, The Netherlands*

Received 6 March 2002; accepted 20 November 2002

Abstract

The present study investigated whether facial EMG measures are sensitive to the effects of fatigue. EMG activity of the corrugator and frontalis muscles was recorded during and after a simulated workday. Fatigue was evaluated in four ways: (a) the building up of fatigue effects during the workday, (b) the building up of fatigue during a test period, (c) examination of after-effects of the workday in two test sessions in the evening, and (d) comparison of subjects with a high-and low-score on an Emotional Exhaustion questionnaire. EMG activity decreased during the workday and increased again in the evening. EMG activity also increased during a test period, reflecting increased mobilization to maintain performance. High-score subjects showed a lower level of EMG activity throughout the entire workday. They reported a higher need for recovery, experienced the workday as more fatiguing, and were less well rested when getting up. EMG measures seem to reflect that high-score subjects have problems with investing sufficient energy to maintain performance during a workday.

© 2003 Elsevier Science B.V. All rights reserved.

Keywords: Fatigue; Facial EMG activity; Emotional exhaustion; Questionnaires

1. Introduction

Fatigue is one of the most frequently reported complaints among work-related problems leading to absence and work incapacity (Foets and Sixma, 1991; Schaufeli and Houtman, 2000; Wessely, 2001). In most current theories fatigue is considered as

* Corresponding author. Tel.: +31-13-466-2366; fax: +31-13-466-2370.

E-mail address: i.j.t.veldhuizen@uvt.nl (I.J.T. Veldhuizen).

a bio-behavioral state an individual is in, which is induced by enduring task performance; it may refer to the state during as well as to the state after that performance (Cameron, 1973; Craig and Cooper, 1992). Fatigue is a multidimensional state ‘only translated to a unitary perception by the unity of consciousness itself’ (Desmond and Hancock, 2001). Some frequent distinctions used to illustrate the multidimensionality are mental versus physical fatigue and acute versus chronic fatigue (Craig and Cooper, 1992; Gawron et al., 2001; Grandjean, 1979). Mental fatigue is a response of mind and body to the reduction in resources due to mental task execution. It warns for the increasing risk of performance failure. Under normal circumstances, people become tired by their everyday work activities, but their energetical¹ resources are sufficient to meet the task demands. However, when a person is working under high levels of (mental) workload and is already fatigued (e.g., at the end of a workday), extra energy to compensate fatigue has to be mobilized through mental effort in order to maintain task performance (Gaillard, 2001; Hockey, 1997; Hockey et al., 1986). The mobilization of extra energy may result into (feelings of) acute fatigue. A subsequent return to physiological and emotional baseline levels is important. Incomplete or slow recovery from workload demands disrupts the energetic homeostasis, which in turn may lead to chronic effects on health and well being (‘slow unwinding’, Frankenhaeuser, 1979; Frankenhaeuser and Johansson, 1986). In the event of incomplete recovery, the effects of high workload demands can accumulate gradually, carry over from one day to the next (Craig and Cooper, 1992; Frankenhaeuser, 1980; Frankenhaeuser and Johansson, 1986; Gaillard, 2001; Ursin, 1980).

Fatigue resists simple measurement, which stems from the multidimensional nature of the condition (Gawron et al., 2001; Desmond and Hancock, 2001; Wessely, 2001). Therefore, fatigue is measured using several different measurement methods varying from performance based, to physiological, biochemical, or subjective measures. In most research fatigue has been measured by means of questionnaires, especially as far as work-related fatigued is concerned (e.g., Checklist Individual Strength (Vercoulen et al., 1999), General Burnout Questionnaire, Maslach Burnout Inventory (Maslach and Jackson, 1986), Shortened Fatigue Questionnaire (Alberts et al., 1997)). Although most of these questionnaires have proven to be valid and reliable, the major disadvantage remains that they are subjective assessment tools. They give limited insight into the causes and mechanisms that produce fatigue, in particular the enduring effects are unknown. Therefore, physiological measures provide important additional information about the biobehavioral state of the subject.

The present study focuses on a long tradition of using tonic EMG activity in irrelevant muscles as an index for fatigue effects. In a classic study, Wilkinson (1962) observed a strong relation between muscle tension and task performance in sleep-deprived subjects. The performance of subjects who showed a small increase in

¹ The term energetical refers to ‘...all energizing mechanisms that regulate the organism and directly or indirectly influence the efficiency of psychological processing’ (Gaillard and Kramer, 2000).

muscle tension was impaired most. Those subjects with a large increase were able to maintain their performance at an acceptable level. Thus, the larger the increase in EMG (muscular tension), the better performance was maintained after sleep loss. This finding suggests that muscle tension reflects the effort that is mobilized by the subjects to overcome their fatigue (Craig and Cooper, 1992). Under demanding conditions, like after a workday, performance level can be maintained by mobilizing extra energy through compensatory mental effort, as signified by an increase in EMG activity levels. In several experiments (Freeman, 1931; Freeman and Lindley, 1931) a high correlation has been found between EMG activity and degree of effort. Subjects with the highest average tonic EMG activity showed the smallest work decrement. Muscle tension was not taken as an indicator of fatigue per se, but rather of the effort applied in performing a task. Van Boxtel and Jessurun (1993) hypothesized that increasing EMG activity in certain facial muscles may be an expression of growing compensatory effort to keep performance at an adequate level. During a 20 min sustained attention task, performance remained stable and was associated with a gradual increase in EMG amplitude (of the frontalis, the corrugator supercilii, and the orbicularis oris inferior muscle), called an EMG gradient (Malmo, 1965). The idea of EMG amplitude as an index of compensatory effort was supported by various studies (Van Boxtel et al., 1997; Veldhuizen et al., 1998; Waterink and Van Boxtel, 1994).

The current study investigated whether tonic EMG activity of the facial muscles reflects differences in fatigue during and after a simulated workday. The aim of this study was to examine whether subjects with and without enduring fatigue complaints, as measured by a questionnaire, differed in level of EMG activity during task performance. The above-mentioned studies show that tonic activity can be considered as an index of the amount of compensatory mental effort, necessary to overcome the fatiguing effects of a workday and maintain performance at a stable level. An EMG gradient is interpreted as an indication of increasing energy mobilization in order to counteract effects of fatigue. In the present study, fatigue was measured using a multi-method approach. Three different measurement methods were used: subjective ratings (questionnaires assessing perceived mental effort, subjective fatigue, and need for recovery), performance indices (reaction times and number of correct responses on a standardized Sternberg memory-scanning task), and EMG activity measures.

EMG activity was measured during the performance of the standardized Sternberg memory-scanning task on six occasions during the simulated workday and the subsequent evening. Fatigue was manipulated in four ways: (a) the building up of fatigue effects during the simulated workday, (b) the effect of time-on-task during the 5-min task session, (c) the after-effects of the workday, i.e., performance and EMG activity in the evening, and (d) the comparison of two subject groups (high/low-score group), differing in the number of enduring fatigue complaints indicated by the score on the emotional exhaustion (EE) scale from the Dutch version of the Maslach Burnout Inventory, administered before the experiment. High-score subjects were expected to have lower levels of EMG activity during task performance than low-score subjects do. Subjects with a high score were expected to

have more problems to mobilize energy, and thus would have problems with compensating their fatigue to counteract the effects of time-on-task. It was also expected that EMG activity during the evening tests would be higher for both groups than during the daytime tests. Since tonic activity can be considered as an index of the amount of compensatory mental effort, necessary to overcome the fatiguing effects of a workday, subjects would probably have to invest more effort in the evening tests in order to maintain performance at a stable level.

2. Method

2.1. Participants

Forty-six undergraduate students participated in the experiment (24 women and 22 men, mean age = 21.7 years). None of the participating students indicated to experience health problems, be under medical treatment or take medication. The two subject groups did not differ with respect to the five major personality factors (extraversion, agreeableness, conscientiousness, emotional stability, and autonomy) as measured by the five-factor personality inventory (FFPI; Hendriks et al., 1999). Subjects participated voluntarily and received (ECTS) credit points for their participation. On the basis of their score on the subscale EE of the Dutch version of the Maslach Burnout Inventory (see questionnaires), subjects were distributed in two groups: high-score group (ten women and 13 men, mean age = 20.2 years) versus low-score group (14 women and nine men, mean age = 23.1 years). The high-score group consisted of participants scoring above the 75th percentile (mean EE score = 2.63, S.D. = 0.51). Participants with a score equal or below the 75th percentile, the low-score group, were designated as control subjects (mean EE score = 1.33, S.D. = 0.50).

2.2. Simulated office

The experiment was carried out in a simulated office with office equipment, including a computer. The experiment lasted an entire day. Several office tasks that collectively made up a fictitious organization of a conference were presented to the subjects in a morning and afternoon work session. The main office tasks were (a) formulating a suitable lecture arrangement for the supposed conference speakers, (b) writing down a publication list of the conference contributions, (c) drawing up a hotel planning for the listed participants, (d) making travelling plans for participants, (e) making all sorts of preparations for the succeeding congress, and (f) correcting multiple fake contributions for the conference book. To increase the realistic character of the simulated workday, subjects were frequently interrupted with small tasks, such as looking up phone numbers and taking notes.

2.3. Probe task

During and after the simulated workday subjects were tested with the Sternberg task (Sternberg, 1966, 1969). The current task was a self-paced short-term memory-searching task (DOS version). This standard task was used to estimate the psychobiological state of the subjects in different phases of the workday. Due to the self-paced character of the task lapses in attention result directly in performance changes. Subjects were instructed to react both as fast and as accurate as possible. The stimuli were presented on the computer screen in front of the subjects. Each trial started with the presentation of the so-called memory set on the computer screen. The memory set contained four randomly selected letters of the alphabet that changed with every trial (varied mapping). In every trial the memory set was a selection from the entire alphabet. The memory set remained on screen for 1500 ms followed by a fixation cross lasting for 500 ms. Immediately after the fixation cross-extinguished, a single probe letter was presented. Subjects had to decide whether or not the probe letter was part of the memory set by pressing a corresponding key on the keyboard. The probe letter remained on screen for maximally 10 s. After responding, subjects received a verbatim feedback message on the screen ('good', 'wrong', or 'too late'). After the feedback stimulus disappeared, the next trial started. The number of correct responses as well as their corresponding reaction times were recorded. Two versions of the task were used: a short test session and a long test session. The short test session consisted of a 5 min task period (*T*), preceded and followed by a 5 min rest period (*R*) [*R* (5 min)–*T* (5 min)–*R* (5 min)]. The long test session consisted of two 25-min task periods surrounded by 5-min rest periods [*R* (5 min)–*T* (25 min)–*R* (5 min)–*T* (25 min)–*R* (5 min)].

2.4. Procedure

The experiment lasted approximately 10 hours and was divided in two parts: a daytime part, from 09:00 h until 17:30 h, and an evening part starting at 18:30 h and lasting until 19:35 h (see Table 1). Before the experiment started the task procedure and program of the day were explained to the subjects. Then, subjects practiced the Sternberg task for 5 min, after which the EMG electrodes were applied. During the day, subjects worked in two 3-h work sessions (one in the morning and one in the afternoon) each consisting of different office tasks in order to simulate a workday. Before and after each work session, subjects executed the short experimental test version (test 1–4, see Table 1). In the evening, subjects executed the long experimental test version (long tests 5 and 6, see Table 1). Subjects were instructed to produce as many correct responses as possible on the experimental tasks.

2.5. Questionnaires

Subjects were asked to complete the following set of questionnaires at home, the day prior to the start of the experiment: (a) the sub-scale EE from the Dutch version of the Maslach Burnout Inventory (MBI-NL; Schaufeli and van Dierendonck, 1994;

Table 1
Schedule of simulated workday

Time of day (h)	Event
09:00–09:45	Training, state questionnaires
09:45–10:00	Test 1 ^a
10:00–13:00	Work session, state questionnaires
13:00–13:15	Test 2 ^a
13:15–14:00	Rest
14:00–14:15	Test 3 ^a
14:15–17:15	Work session, state questionnaires
17:15–17:30	Test 4 ^a
17:30–18:30	Rest
18:30–19:35	Long tests ^b (tests 5 and 6), state questionnaires

^a Short test session [*R* (5 min)–*T* (5 min)–*R* (5 min)].

^b Long test session [*R* (5 min)–*T* (25 min)–*R* (5 min)–*T* (25 min)–*R* (5 min)].

MBI; Maslach and Jackson, 1986), (b) the sub-scale Need for recovery of the ‘Questionnaire assessing work experience and work appreciation’ (VBBA; Van Veldhoven and Meijman, 1994), and (c) questions addressing how well rested subjects felt, in general, in the morning, and about the average number of hours sleep each night.

The EE scale indicates the amount of enduring fatigue. The EE score is the sum of five items, each with a 7-point rating scale ranging from 0 (never) to 6 (always). The items address work experience and feeling. The scale scores range from 0 to 6 with a high score signaling a higher amount of enduring fatigue. The psychometric properties are good (Schaufeli and van Dierendonck, 1994). For the current study the MBI-NL was adapted for students by substituting in each item the word ‘work’ by ‘study’. The need for recovery scale contains 11 dichotomous items (yes/no). The scale scores range from 0 to 10 with a high score signaling a higher need for recovery. The scale has a Cronbach’s alpha of 0.87. The question ‘In general, how well rested do you feel in the morning?’ was assessed by a dichotomous rating scale (‘well rested’, ‘not well rested’). The average number of hours sleep each night was a direct question filled in by the subjects.

On the day the experiment took place, subjects completed the following set state questionnaires at four different times (see Table 1): the Shortened Fatigue Questionnaire (SFQ), the scale for perceived load (SPL), the rating scale mental effort (RSME), and the checklist individual strength (CIS-20).

The SFQ (Alberts et al., 1997) assesses the intensity of physical fatigue. It contains four items with a 7-point Likert scale (ranging from 1 (yes, that is true) to 7 (no, that is not true)). The scale scores range from 4 to 28. The reliability of the SFQ is good (Cronbach’s alpha 0.92).

The SPL (Van Veldhoven and Meijman, 1994) measures feelings of fatigue during work. The SPL contains 16 items that are rated on a 5-point scale. Each item contains two opposing statements and subjects have to indicate on a 5-point scale,

which of the two statements corresponds more with their momentary physical state. The scale scores range from 0 to 48. The SPL has good reliability coefficients.

The RSME (Zijlstra, 1994) measures subjective ratings of perceived mental effort. The RSME is a one-dimensional visual-analogue scale containing nine different verbal categories forming anchor points expressing different levels of mental effort. The scale ranges from 0 to 150. The RSME shows systematic relations with task difficulty and performance measures.

The CIS-20 (Vercoulen et al., 1994) measures subjective feelings of fatigue and related behavioral aspects. The CIS contains 20 items that make up four subscales: subjective experiences of fatigue (eight items), concentration (five items), motivation (four items) and physical activity level (three items). All items are scored on a 7-point Likert scale (ranging from 1 (yes, that is true) to 7 (no, that is not true)). The CIS-20 has a good reliability coefficient (Cronbach's alpha 0.90). In the present study the motivation (CIS-m) and concentration (CIS-c) subscales were administered. The scale scores of both subscales range from 4 to 28, and from 5 to 35, respectively.

2.6. EMG recording and analysis

All physiological signals were recorded with the VitaPort 2 System developed by TEMEC Instruments. The VitaPort 2 System was expanded with two modules, the 8-channel universal amplifier module with multi-connector and the 18 channel Polysomnographmodule with multi-connector.

EMG activity was bipolarly recorded by means of Ag/AgCl surface electrodes with contact area and housing of 2 and 11-mm diameter, respectively. Electrodes were attached to the skin with electrode centers 15-mm apart. The reference electrode was an ECG snap lead electrode, placed on the middle of the forehead. EMG activity was recorded on the left-hand side from the facial corrugator supercilii and the frontalis muscles. Electrode positions were chosen in accordance with the guidelines presented by Fridlund and Cacioppo (1986). EMG activity was recorded during each entire test session, thus including rest and task periods.

EMG signals were pre-amplified with a factor 1000 and analogue band-pass filtered with a -3 dB high-pass cut-off frequency at 10.61 Hz and a -3 dB low-pass cut-off frequency at 400 Hz. EMG signals were then digitized by means of a 12-bit AD-converter with a sample frequency of 1024 Hz. Subsequently, the data were digitally high-pass filtered with a -3 dB cut-off frequency of 32 Hz (in order to lose unwanted movements artifacts). Ensuing, the data were stored on a 340 MB PCMCIA hard disk for VitaPort 2. The data were then further processed using SAS for WINDOWS, Release 6.12 TS Level 0025. First, the data were filtered using a notch filter with -3 dB cut-off frequency points at 0.0438 and 0.0558 Hz, respectively. Ensuing, the data were full-wave linearly rectified and smoothed by means of low-pass filtering (-3 dB cut-off frequency at 38.4 Hz, > 40 dB down/octave). Finally, the measurement points were integrated using 1 s periods.

In the short test sessions, the first and last 30 s integrated data points from each rest and task period were omitted resulting in 4 min (240 integrated data points) recorded EMG data per period (4 min rest, 4 min task, 4 min rest). For the analysis

of EMG activity, the mean EMG amplitude per 60 s was calculated, leading to four mean amplitude scores for each task period. In addition to the amplitude scores, difference scores with respect to the rest periods were determined. Before determining the difference scores, the presence of group differences in the rest periods was checked. Since no group differences were found, the four mean amplitude scores were converted into difference scores by subtracting the surrounding mean rest values from each average, thus resulting into four difference scores.

For the long test session, the same data reductions and procedures were used. This resulted in 4-min recorded EMG data per rest period and 24 min recorded EMG per task period. For the analysis of EMG activity, the mean amplitude per 240 s was calculated, leading to six mean amplitude scores for each task period. In addition to the amplitude scores, rest-task difference scores with respect to the rest periods were determined. Before determining the difference scores, the presence of group differences in the rest periods was checked. Since no group differences were found, the six mean amplitude scores were converted into rest-task difference scores by subtracting the surrounding mean rest values from each average, thus resulting into six difference scores.

The analysis was performed on the mean amplitude scores and on the difference scores. In this way we are able to look into differences between both subject groups in initial EMG activity levels as well as to explore a task effect in groups while leveling out these initial differences ascribed to group participation. The results of the analyses will be the same for amplitude and difference scores with the exception for between subject effects. Since the EMG data are standardized with respect to the surrounding mean rest values, the presence of group differences in the rest periods is checked in a separate analysis.

2.7. *Statistical analysis*

EMG activity and performance measures were analyzed with the multivariate analysis of variance for repeated measures (MANOVA). For the analysis of EMG activity, MANOVA's were performed on both the difference scores and the amplitude scores. Two different analyses were performed. The first analysis was executed on the daytime tests with tests (test 1–4) and periods (time course over the four averaged data points within a test) as within-subjects variables and group (high-vs. low-score) as the between-subjects variable. The second analysis was executed on the evening tests with tests (test 5–6) and periods (time course over the six averaged data points within a test) as within-subjects variables and group (high-vs. low-score) as the between-subjects variable. The effect of tests on the difference and amplitudes scores was examined by transforming the test levels into linear and quadratic trend contrast scores by computing orthogonal polynomials. Significant effects of group on these linear and quadratic trends across task were further investigated by means of simple effects tests in order to test trend components in both groups. In order to assess the effect of periods during the tests, orthogonal polynomial contrasts were computed across the difference and amplitude scores in order to assess linear and quadratic increases in EMG activity during the test. Significant effects of these

contrasts demonstrate the presence of an EMG gradient. Main effects of group and test on these trend components were further investigated for each level of group and test separately. The effect of subject group was investigated by the main group effect.

The presence of group differences in EMG activity in the rest periods was analyzed using MANOVA's, with rest (rest periods of test 1–6) as the within-subjects variable and group as the between-subjects variable. Analyses were executed on the surrounding mean rest values.

An additional analysis was executed to compare the EMG activity level in the long evening test session with the activity level in the last daytime test (test 4). The difference in mean activity of the first evening test was compared with the mean activity of test 4. The difference scores for test 4 were subtracted from the difference scores for test 5. An independent sample *t*-test was executed on these subtracted scores, with group as the grouping variable.

The 0.05 probability level was adopted as significance criterion in all tests. Since we expected that high-score subjects would have more problems in compensating their fatigue and thus show less EMG activity in comparison with the control subjects, we used a one-tailed testing procedure for the differences between groups. Since we also expected an overall increase in EMG activity during the day as well as during a test, the within-subjects variables test and period were also subjected to a one-tailed test.

For the analysis of the task performance measures, number of correct responses and reaction times, the same MANOVA's were executed but without the factor periods. The state questionnaires were analyzed using a MANOVA with administration of questionnaires (four administrations during the workday) as within-subjects variable and group (high- vs. low-score group) as the between-subjects variable. The trait questionnaires were analyzed using a one-way ANOVA with Questionnaire (each trait questionnaire is only once administered) as within-subjects variable and group (high- vs. low-score group) as the between-subjects variable.

3. Results

3.1. EMG activity

As is illustrated in Fig. 1, the activity pattern of the two muscles was quite similar. The results of the analysis on the amplitude scores in the four short test sessions show a clear effect of test for the corrugator and frontalis muscle as shown by a negative linear trend and a significant positive quadratic trend across tests (see Table 2 for the statistical results). No significant interaction was found between group and test, and no group effect for both trends. The presence of the trend components demonstrates a curvilinear decrease in mean EMG activity during the day. Fig. 1 shows a reduction in mean activity during the morning and the beginning of the afternoon (test 1–3), and an increase in mean activity towards the end of the afternoon (test 4). The results of the trend analysis on the EMG amplitudes during a test, are presented in Fig. 2. A significant positive linear trend component was found

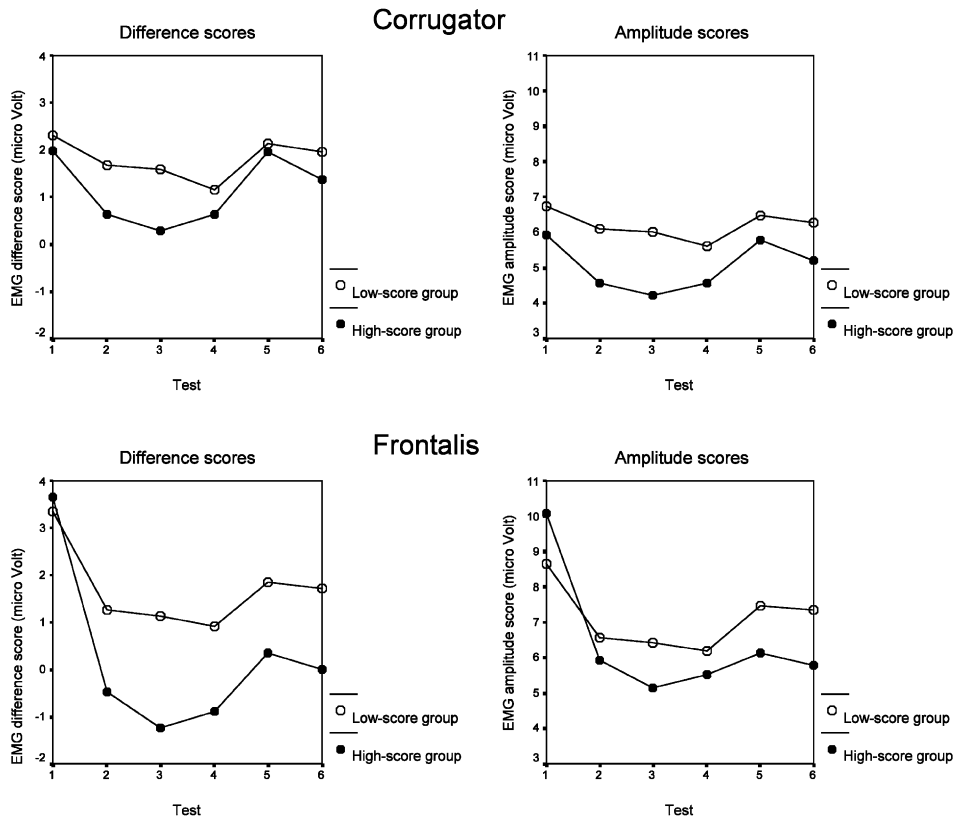


Fig. 1. Mean EMG activity during the Sternberg tests, separately for the corrugator and frontalis muscle, for the amplitude and difference scores, and for the low-score and high-score group.

for the corrugator and frontalis muscle. This demonstrates a continuous increase (EMG gradient) in activity during each test. The EMG gradient was present during each test. No significant interaction was found between group and periods, meaning that the trend component was equal in both groups. A significant overall group effect was found for the corrugator muscle. The high-score group showed less EMG activity than the low-score group. This effect was not significant for the frontalis muscle. The results for the difference scores were the same as for the amplitude scores, with the exception of the overall group difference. The high-score group showed lower EMG difference scores for the corrugator muscle as well as for the frontalis muscle.

The results of the analysis on the two long test sessions in the evening are also presented in Fig. 1. The amplitude scores of the corrugator muscle showed a clear effect of test as indicated by a significant negative linear trend across tests. As can be seen in Fig. 1 the mean corrugator activity decreased during the evening tests. No effect of test was found for the frontalis muscle, which means that EMG activity

Table 2

F values for the MANOVA's on corrugator and frontalis muscle EMG activity, with repeated measures of test and periods and the between-subjects variable group

			Corrugator	Frontalis
Daytime	Test (1–4)	Linear trend	10.99**	10.93**
		Quadratic trend	6.18**	11.46**
	Periods	Linear trend	29.38***	2.74*
		Quadratic trend	1.70	1.32
	Group		<i>2.88*</i>	<i>0.06</i>
			<u>2.58</u>	<u>8.94**</u>
Evening	Test (5–6)	Linear trend	5.29*	1.20
		Quadratic trend	22.08***	10.36**
	Periods	Linear trend	16.24***	1.39
		Quadratic trend	0.90	1.99
	Group		<i>0.28</i>	<i>6.39**</i>
			<u>0.28</u>	<u>6.39**</u>

For all tests, $df = 1.44$. The MANOVA's on the amplitude and difference scores generate the same results with the exception of the overall group difference. Italicized values indicate amplitude score results, underlined values the difference score results. * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$.

remained on the same level during both tests. No significant interaction was found for both muscles between group and test. Trend analysis of activity displayed during tests, revealed a significant positive linear trend component and a significant negative quadratic trend component during each test for the corrugator muscle, and a significant positive linear trend component for the frontalis muscle. This demonstrates a continuous increase in corrugator and frontalis activity (EMG gradient) during a test (see Fig. 2). No significant interaction was found between group and periods, meaning that the trend component was equal in both groups. No significant overall group difference was found for the corrugator muscle. The amplitude of the frontalis muscle showed a tendency to differ between groups. The high-score group tended to show lower EMG amplitudes than the low-score group. For the difference scores, no group difference was found for the corrugator muscle. The amplitude of the frontalis muscle did differ between groups. For the high-score group, the difference scores were smaller than for the low-score group.

The results of the analysis on the surrounding rest values showed no group differences for the corrugator, $F(1,44) = 0.73$, $P = 0.40$, and the frontalis muscle, $F(1,44) = 0.50$, $P = 0.48$. No significant interactions were found between group and rest for both muscles, meaning that during the day, both groups showed equal rest values.

The t -test comparing the EMG activity in the long evening test session with the activity in the last daytime test (test 4) showed a significant increase for the corrugator, $t = 3.54$, $P < 0.001$, and frontalis muscle, $t = 2.43$, $P < 0.05$. The increase was the same for the two groups.

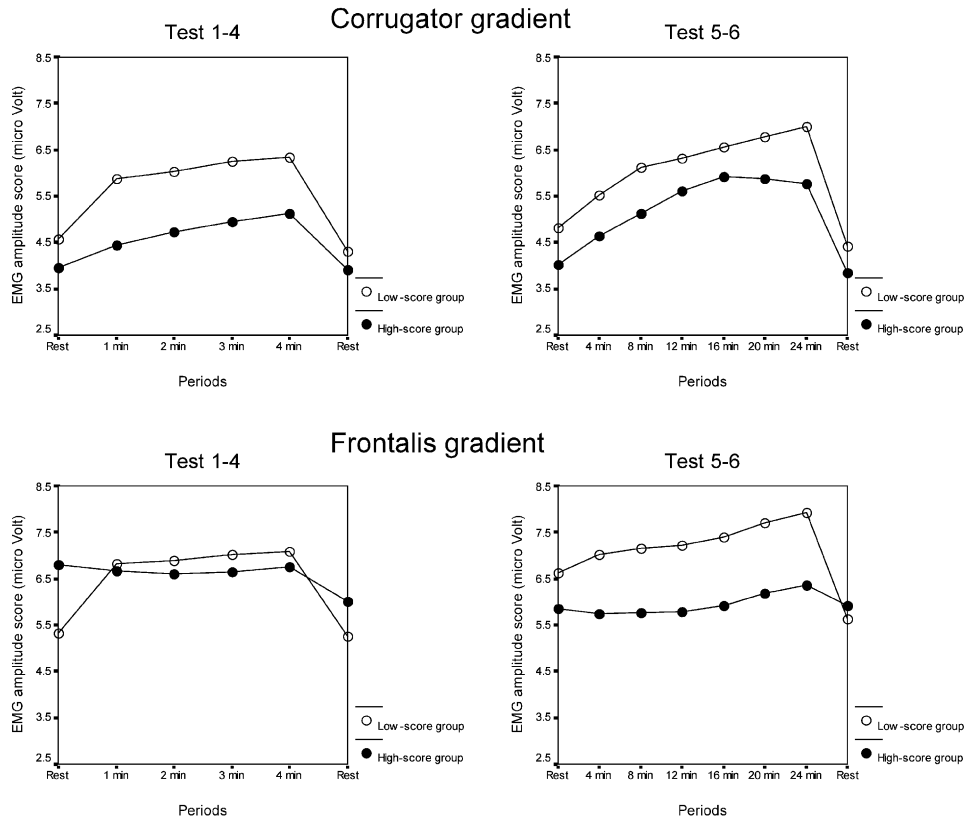


Fig. 2. Mean EMG gradients for the amplitude scores during test 1–4 and test 5–6, separately for the corrugator and frontalis muscle, and for the low-score and high-score group.

3.2. Task performance data

The results of the analysis on the reaction times in the test sessions during the day and evening are presented in Fig. 3 and in Table 3. The reaction times in the test sessions during the day, did not differ between the two groups. In both groups, reaction times decreased during the experiment and trend analysis showed both a negative linear and a positive quadratic trend component. Reaction times decreased strongly during the morning and stabilized during the afternoon. The analysis on the two long tests in the evening showed that the high-score group had slower reactions. In both groups, no differences were found between the first and second long test.

Fig. 3 also displays the number of correct responses. The analysis on the four test sessions showed no differences in the number of correct responses between the two groups. The number of correct responses increased during the four tests as shown by a positive linear trend and a negative quadratic trend. The analysis on the number of correct responses of the two long tests in the evening showed a significant difference between subject groups. The high-score group had a smaller number of correct

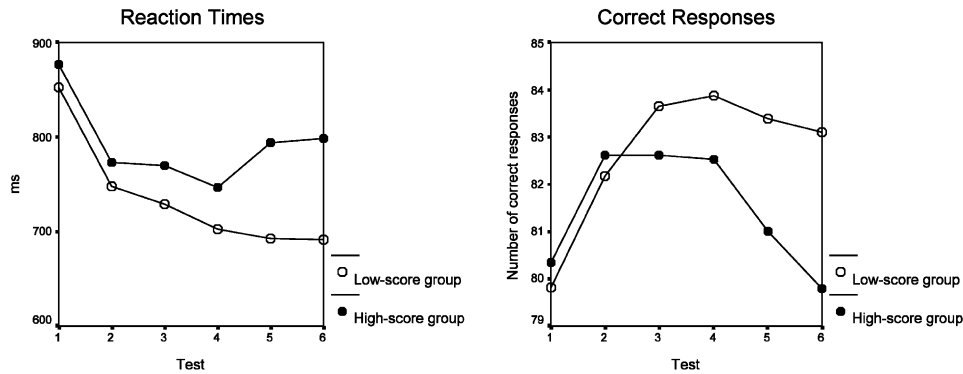


Fig. 3. Mean reaction times and number of correct responses for each Sternberg test for the low-score and high-score group.

Table 3

F values for the MANOVA's on task performance (reaction times and number of corrects responses), with repeated measures of test and the between-subjects variable group

			Reaction times	Correct responses
Daytime	Test (1–4)	Linear trend	38.85***	30.00***
		Quadratic trend	15.75***	7.06*
	Group		0.51	0.10
Evening	Test (5–6)	Linear trend	0.02	1.83
	Group		5.82*	6.136**

For all tests, $df = 1.44$. * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$.

responses. Although the results suggest a decrease in performance for the high-score group, this interaction was not significant. No differences in the number of correct responses were found between the first and second long test.

3.3. Questionnaires

The outcomes of the analyses on the state questionnaires are presented in Tables 4 and 5. Subjective ratings of mental effort (RSME scores) did not differ between the low- and high-score group. Results showed the presence of a positive linear trend as well as a negative quadratic trend across the four administrations of the effort questionnaire. The trends were equal for both groups and indicated an increase in perceived subjective effort during the day.

Fig. 4 depicts the results for the four administrations of the SPL, as well as the SFQ. The experience of physical fatigue, as measured by the SFQ, did differ between the low- and high-score group. The high-score group experienced more fatigue. Towards the end of the experiment all subjects experienced more fatigue. Trend analysis revealed for both groups the presence of a positive linear trend as well as a negative quadratic trend.

Table 4

F values for the MANOVA's on the state questionnaires, with repeated measures of administration of questionnaires (4) and the between-subjects variable group

	RSME	SFQ	SPL	CIS-m	CIS-c
<i>Administration</i>					
Linear trend	155.94***	37.02***	31.20***	22.02***	17.24***
Quadratic trend	5.83*	8.84**	17.99***	0.20	1.84
Group	0.92	7.87**	5.45*	2.44	4.74*

For all tests, $df = 1.44$. RSME, rating scale mental effort; SFQ, short fatigue questionnaire; SPL, scale for perceived load; CIS-m, checklist individual strength, subscale motivation; CIS-c, checklist individual strength, subscale concentration. * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$.

The intensity of mental fatigue, as measured by the SPL, differed between groups. The high-score group showed more fatigue than the low-score group. Furthermore, scores were also affected by the duration of the experiment as shown by a positive linear trend component and a negative quadratic trend component across the four administrations of the questionnaire. Both groups experienced more fatigue when the workday progressed.

The analysis executed on the motivation subscale of the CIS-20 demonstrated no group difference. Results did show a positive linear trend indicating an increase in motivation problems during the day. The analysis on the subscale concentration of the CIS-20, did show a significant group difference. High-score subjects had more problems maintaining their concentration during the day. The results also demonstrated a significant positive linear trend signifying that subjects gradually experienced more concentration problems during the workday.

Table 6 shows that the high-score group showed a higher need for recovery than the low-score group. The same figure also illustrates that high-score subjects felt in general less well rested in the mornings.

Finally, subjects in the high-score group slept, in general, fewer hours than subjects in the low-score group.

4. Discussion

The present study shows that facial EMG measures differentiate between subjects with and without enduring fatigue complaints as indicated by the EE scale of the Burnout questionnaire. During all six tests, subjects with many complaints displayed less activity than subjects with few complaints. Mean muscle activity of the frontalis muscle gradually decreased during the day, whereas this activity increased in the evening. The EMG activity for both groups was higher in the evening tests than in the last daytime test. The gradually increasing EMG activity during a test was labeled the EMG gradient (e.g. Van Boxtel and Jessurun, 1993). The EMG gradients were similar in both groups, although the gradients in the high-score group started

Table 5
Mean values and standard deviations (in parentheses) for the four administrations (Adm) of the state questionnaires during the workday, for the high-score (HS) and low-score (LS) group

	RSME		SFQ		SPL		CIS-m		CIS-c	
	HS	LS	HS	LS	HS	LS	HS	LS	HS	LS
Adm 1	11.90 (11.88)	11.87 (9.03)	11.17 (4.81)	14.74 (3.80)	13.26 (6.96)	15.91 (6.97)	8.78 (4.23)	11.04 (3.02)	13.74 (4.10)	13.13 (5.17)
Adm 2	43.43 (19.49)	47.39 (20.20)	11.43 (4.49)	14.00 (4.81)	13.48 (4.83)	15.91 (4.95)	10.43 (4.93)	11.56 (3.77)	13.91 (4.30)	15.96 (4.57)
Adm 3	51.13 (20.84)	57.00 (20.43)	12.83 (5.18)	17.35 (4.70)	14.87 (6.26)	17.78 (6.97)	11.17 (4.95)	13.52 (4.70)	14.78 (5.13)	18.26 (6.87)
Adm 4	72.43 (30.77)	80.26 (33.55)	15.83 (5.73)	18.83 (5.44)	19.39 (7.06)	25.61 (9.19)	12.74 (5.99)	14.65 (6.44)	16.39 (5.15)	20.39 (7.15)

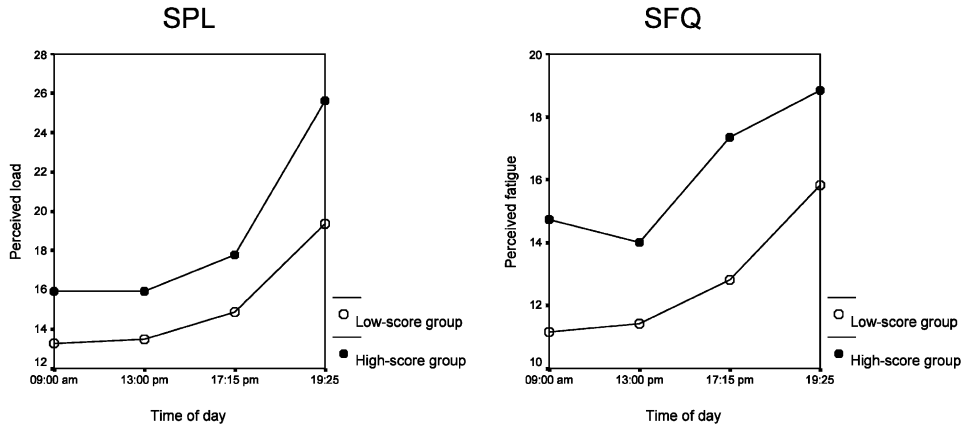


Fig. 4. Results of the SPL and the SFQ for the low-score and high-score group.

Table 6

Results for the subject groups of the questionnaire need for recovery (mean value) and of the questions addressing 'feeling well rested' (expressed in percentages) in the mornings, and hours sleep each night (mean value)

	Group		<i>F</i>
	Low-score	High-score	
Need for recovery	2.70	3.83	2.72*
Feeling 'well rested'	73.91	34.78	8.03**
Hours sleep	8.17	7.65	2.84*

F values correspond with the executed ANOVA's. For all tests, *df* = 1.44. **P* < 0.05; ***P* < 0.01.

on a lower level. The corrugator muscle showed overall the same pattern as the frontalis muscle, except that the group effect in the evening was not significant.

The EMG gradients were interpreted as a sign of growing compensatory mental effort to maintain task performance (e.g. Van Boxtel and Jessurun, 1993; Waterink and Van Boxtel, 1994). EMG gradients were present in both subject groups, which indicates that both groups strived to maintain their performance by exerting more effort. The larger EMG activity during the evening tests can also be considered as an indication of compensatory mental effort, necessary to overcome the fatiguing effects of the workday. Subjects have to invest more effort in the evening tests in order to maintain performance at a sufficient level.

The smaller EMG activity in subjects with complaints suggests that they have problems to invest sufficient energy. This is supported by the performance results. They react slower and produce a smaller number of correct responses. Although this difference between the groups only reaches significance in the evening, the trend is already present during daytime. High-score subjects seem to be just able to perform

during daytime, but their resources come to end in the evening, although they tried to invest more effort.

That subjects scoring high on EE have more problems to maintain a good performance is also supported by the results of the questionnaires. They experience more physical and mental fatigue during the entire day, and report to have more problems maintaining their concentration. However, high-score subjects do not experience the simulated workday as demanding more mental effort. Both groups show the same increase in mental effort during the day. This appears to be in contradiction with the other questionnaires measuring fatigue and perceived mental load. Apparently, finding a task effortful does not necessarily mean that subjects find it also more fatiguing. The judgement of effort appears to be related to the difficulty of the task as such and not to problems subjects may have in executing the task. One could argue that a lack of motivation might have caused the effects in the EMG and questionnaire results. However, no differences between the groups were found on the sub-scale motivation of the CIS-20.

High-score subjects have a higher need for recovery, do not feel ‘well rested’ in the mornings, and sleep less than the other subjects. This result was also found in a study (Zijlstra and de Vries, 2000) that investigated the relation between burnout and work-related variables. Despite their larger need for recovery, high-score subjects sleep less than low-score subjects, thereby making less use of the possible beneficial recovery effects due to sleep. In a study done by Sluiter et al. (1999) similar relationships were found. They showed that need for recovery was a major predictor of sleep complaints and complaints of EE. Melamed et al. (1999) found that workers with burnout symptoms had more sleep disturbances and complaints of ‘waking up exhausted’ than workers without burnout symptoms. The present results suggest a process of mutual reinforcing factors. The cumulating fatiguing effects of a day’s work demand recovery. However, high-score subjects sleep less, thereby starting the following day ‘less rested’, which in turn enlarges the fatigue effects the next day. Through this process fatigue effects accumulate, which may result in burnout. This view supports the idea of reduced adaptiveness of psychobiological functions. This notion is supported also by the larger reduction of EMG activity after the completion of the two long tests in the evening (see Fig. 2). This reduction is larger in the low-score group than in high-score group, which suggests a better adaptation to task demands and faster recovery to rest values. A similar effect was found for blood pressure in hypertensives (Frankenhaeuser, 1986, Fig. 4).

Although the results of the present study yield a consistent picture, there are limitations to the study. The experiment was set up to simulate a workday. Realistic simulation of a workday is difficult, however. A field study would have been better in this respect but would have raised other problems, such as limited controllability of the task environment. It should be noted that the present subjects were selected from a ‘normal’ student population, which should be kept in mind when extrapolating the results to other groups.

It appears that subjects, scoring high on EE, have more problems with investing sufficient energy to maintain performance during a workday. In general, they have a higher need for recovery and feel less well rested when getting up. The difference in

EMG activity found in both the corrugator and frontalis muscles shows a fairly stable pattern, throughout the entire day. As indicated by the fatigued subjects themselves, they find the simulated workday more fatiguing, physically and mentally, than the subjects do with a low-score on EE. The results of this study show converge evidence between subjective, performance, and physiological measures. They all contribute to the insight in the mechanisms that play a role in the development of burnout symptoms. Since facial EMG measures appear to be sensitive to the effects of fatigue, they provide a tool to evaluate the energy mobilization during prolonged working periods.

Acknowledgements

The present study was carried out under the Dutch Concerted Research Action 'Fatigue at Work' of the Netherlands Organization for Scientific Research (NWO) that funded this project.

References

- Alberts, M., Smets, E.M.A., Vercoulen, J.H.M.M., Garssen, B., Bleijenberg, G., 1997. 'Verkorte vermoeidheidsvragenlijst': een praktisch hulpmiddel bij het scoren van vermoeidheid. *Ned. Tijdschr. Geneesk.* 141, 1526–1530.
- Cameron, C., 1973. A theory of fatigue. *Ergonomics* 16, 633–648.
- Craig, A., Cooper, R.E., 1992. Symptoms of acute and chronic fatigue. In: Smith, A.P., Jones, D.A. (Eds.), *Handbook of Human Performance*. Academic Press, San Diego, pp. 289–340.
- Desmond, P.A., Hancock, P.A., 2001. Active and passive fatigue states. In: Hancock, P.A., Desmond, P.A. (Eds.), *Stress, Workload, and Fatigue*. Human Factors in Transportation. Lawrence Erlbaum Associates, Mahwah, NJ, pp. 455–465.
- Foets, M., Sixma, H., 1991. Nationale studie naar ziekten en verrichtingen in de huisartsenpraktijk/ [National study into diseases and operations in medical practice], Utrecht: Nederlands Instituut voor Onderzoek van de Eerstelijnsgezondheidszorg (NIVEL).
- Frankenhaeuser, M., 1979. Psychoneuroendocrine approaches to the study of emotion as related to stress and coping. In: Howe, H.E., Dienstbier, R.A. (Eds.), *Nebraska Symposium on Motivation* 1978. University of Nebraska Press, Lincoln, pp. 123–161.
- Frankenhaeuser, M., 1980. Psychoneuroendocrine approaches to the study of stressful person–environment transactions. In: Selye, H. (Ed.), *Selye's Guide to Stress Research*, vol. I. Van Nostrand Reinhold, New York, pp. 46–70.
- Frankenhaeuser, M., 1986. A psychobiological framework for research on human stress and coping. In: Appley, M.H., Trumbull, R. (Eds.), *Dynamics of Stress: Physiological, Psychological, and Social Perspectives*. Plenum Press, New York, pp. 101–116.
- Frankenhaeuser, M., Johansson, G., 1986. Stress at work: psychobiological and psychosocial aspects. *Int. Rev. Appl. Psychol.* 35, 287–299.
- Freeman, H.L., 1931. Mental activity and the muscular process. *Psychol. Rev.* 38, 428–449.
- Freeman, G.L., Lindley, S.B., 1931. Two neuro-muscular indices of fatigue. *J. Exp. Psychol.* 14, 567–605.
- Fridlund, A.J., Cacioppo, J.T., 1986. Guidelines for human electromyographic research. *Psychophysiology* 23 (5), 567–589.
- Gaillard, A.W.K., 2001. Stress, workload, and fatigue as three biobehavioral states: a general overview. In: Hancock, P.A., Desmond, P.A. (Eds.), *Stress, Workload, and Fatigue*. Lawrence Erlbaum Associates, Mahwah, NJ, pp. 623–640.

- Gaillard, A.W.K., Kramer, A.F., 2000. Theoretical and methodological issues in psychophysiological research. In: Backs, R.W., Boucsein, W. (Eds.), *Engineering Psychophysiology, Issues and Applications*. Lawrence Erlbaum Associates, Mahwah, NJ, pp. 31–58.
- Gawron, V.J., French, J., Funke, D., 2001. An overview of fatigue. In: Hancock, P.A., Desmond, P.A. (Eds.), *Stress, Workload, and Fatigue*. Lawrence Erlbaum Associates, Mahwah, NJ, pp. 581–595.
- Grandjean, E., 1979. Fatigue in industry. *Br. J. Ind. Med.* 36, 175–186.
- Hendriks, A.A.J., Hofstee, W.K.B., De Raad, B., 1999. The five-factor personality inventory (FFPI). *Personality Individual Diff.* 27, 307–325.
- Hockey, G.R.J., 1997. Compensatory control in the regulation of human performance under stress and high workload: a cognitive-energetical framework. *Biol. Psychol.* 45, 73–93.
- Hockey, G.R.J., Coles, M.G.H., Gaillard, A.W.K., 1986. Energetical issues in research on human information processing. In: Hockey, G.R.J., Gaillard, A.W.K. (Eds.), *Energetics in Human Information Processing*. Nijhoff, Dordrecht, pp. 3–21.
- Malmo, R.B., 1965. Physiological gradients and behavior. *Psychol. Bull.* 64, 225–234.
- Maslach, C., Jackson, S.E., 1986. *The Maslach Burnout Inventory: Manual Edition*. Consulting Psychologists Press, Palo Alto, CA.
- Melamed, S., Ugarten, U., Shirom, A., Kahana, L., Lerman, Y., Froom, P., 1999. Chronic burnout, somatic arousal and elevated salivary cortisol levels—a review of the empirical evidence. *J. Psychosom. Res.* 46, 591–598.
- Schaufeli, W., van Dierendonck, D., 1994. Burnout, een begrip gemeten: De Nederlandse versie van de Maslach Burnout Inventory (MBI-NL)/[Burnout-The measurement of a concept: the Dutch version of the Maslach Burnout Inventory (MBI-NL)]. *Gedrag Gezondheid* 22, 153–172.
- Schaufeli, W., Houtman, I., 2000. Psychische vermoeidheid en werk. In: Houtman, I.L.D., Schaufeli, W.B., Taris, T. (Eds.), *Psychische Vermoeidheid en Werk*. NWO/Samsom, Alpen aan den Rijn, The Netherlands, pp. 19–36.
- Sluiter, J.K., Van der Beek, A.J., Frings-Dresen, M.H.W., 1999. The influence of work characteristics on the need for recovery and experienced health: a study on coach drivers. *Ergonomics* 42, 573–583.
- Sternberg, S., 1966. High-speed scanning in human memory. *Science* 153, 652–654.
- Sternberg, S., 1969. Memory-scanning: mental processes revealed by reaction-time experiments. *Am. Psychologist* 57, 421–457.
- Ursin, H., 1980. Personality, activation and somatic health: a new psychosomatic theory. In: Levine, S., Ursin, H. (Eds.), *Coping and Health*. Plenum Press, New York, NY, pp. 259–279.
- Van Boxtel, A., Jessurun, M., 1993. Amplitude and bilateral coherency of facial and jaw-elevator EMG activity as an index of effort during a two-choice serial reaction task. *Psychophysiology* 30, 589–604.
- Van Boxtel, A., Waterink, W., Veldhuizen, I.J.T., 1997. Tonic facial EMG activity as an index of mental effort: effects of work rate, time-on-task, and achievement motivation. *J. Psychophysiol.* 11, 91.
- Van Veldhoven, M., Meijman, T., 1994. Het meten van psychosociale arbeidsbelasting met en vragenlijst. *De vragenlijst Beleving en Beoordeling van de Arbeid. Tijdschrift voor Bedrijfs Verzekeringsgeneeskunde* 2, 229–230.
- Veldhuizen, I.J.T., Van Boxtel, A., Waterink, W., 1998. Tonic facial EMG activity during sustained information processing: Effects of workload and achievement motivation. *J. Psychophysiol.* 12, 188–189.
- Vercoulen, J.H.M.M., Swanink, C.M.A., Fennis, J.F.M., Galama, J.M.D., Meer van der, J.W.M., Bleijenberg, G., 1994. Dimensional assessment of chronic fatigue syndrome. *J. Psychom. Res.* 38, 383–392.
- Vercoulen, J.H.M.M., Alberts, M., Bleijenberg, G., 1999. De Checklist Individual Strength (CIS). *Gedragstherapie* 32, 131–136.
- Waterink, W., Van Boxtel, A., 1994. Facial and jaw-elevator EMG activity in relation to changes in performance level during a sustained information processing task. *Biol. Psychol.* 37, 183–198.
- Wessely, S., 2001. Chronic fatigue: symptom and syndrome. *Ann. Intern. Med.* 134, 838–843.
- Wilkinson, R.T., 1962. Muscle tension during mental work under sleep deprivation. *J. Exp. Psychol.* 64 (6), 565–571.
- Zijlstra, F.H.R., 1994. *Efficiency in Work Behavior: A Design Approach for Modern Tools*. Delft University Press, Delft.

- Zijlstra, F., de Vries, J., 2000. Burnout en de bijdrage van socio-demografische en werkgebonden variabelen. In: Houtman, I.L.D., Schaufeli, W.B., Taris, T. (Eds.), *Psychische Vermoeidheid en Werk*. NOW/Samsom, Alphen aan den Rijn, pp. 83–95.